

ELECTRIC DOWNHOLE SAFETY VALVE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Provisional Application Serial No. 60/437,070, filed December 30, 2002 and entitled "Electric Downhole Safety Valve," which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

Field of the Invention

[0001] The present invention relates generally to downhole safety valves and more particularly to a downhole safety valve that is electrically operated.

BACKGROUND OF THE INVENTION

[0002] The invention relates to a surface controlled subsurface safety valve (SCSSV) for a subterranean well and, more particularly, to a safety valve utilizing an electrical actuation mechanism controlled from the surface or by a downhole intelligent controller.

[0003] Oil and gas wells typically employ at least one safety valve that can be actuated to stop or control the flow of fluid through a pipe. These valves are normally positioned downhole to close the bore of the tubing string extending from one or more production zones to the well surface. Safety valves of this type include a spring that biases the valve to a fail-safe mode, such that an interruption in the force acting to keep the valve open will cause the valve to close.

[0004] Conventional downhole safety valves are hydraulically operated. As oil and gas reserves are developed in deepwater, however, the column of fluid needed for hydraulic actuation becomes impractically long. Specifically, the hydrostatic head developed in a conventional hydraulically controlled valve results in high operating pressures and requires an unworkably large failsafe spring.

[0005] Because of the problems with hydraulically controlled safety valves, electrically operated safety valves are an attractive alternative. In addition, intelligent completion systems are being developed that are equipped with a variety of electrically driven flow control devices. Hence, it is currently desirable to provide an all-electric control system and remove the requirement for any

hydraulic supply. Electrically controlled downhole safety valves have been developed, but they generally require high power consumption and/or unfavorably large geometry, and are vulnerable to problems with electrical connections to the surface.

[0006] Hence, it remains desirable to provide an electrically operated downhole safety valve that can operate effectively and reliably at deep setting depths, using available power downhole.

SUMMARY OF THE INVENTION

[0007] The present invention provides an electrically operated downhole safety valve that can operate effectively and reliably using available power downhole. In a preferred embodiment, the present system fits into a casing no larger than would be required for a comparable hydraulic unit.

[0008] The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a more detailed description of the preferred embodiments of the present invention, reference will now be made to the accompanying drawings, wherein:

Figure 1 is a schematic cross-section of a device constructed in accordance with a preferred embodiment of the present invention, showing the valve in a closed position;

Figure 2 is a schematic cross-section of the device of Figure 1, showing the valve in a open position;

Figure 3 is a cross-section taken along lines 3-3 of Figure 2; and

Figures 4 and 5 are cross-sections taken along lines 4-4 and 5-5 of Figure 2, showing the restraining mechanism in its de-energized and energized states, respectively.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0010] Referring initially to Figure 1,

Referring initially to Figure 1, a device constructed in accordance with a preferred embodiment of the present invention comprises a generally cylindrical body 10 having a central bore 12 therethrough and a concentric flow tube 50 slidably mounted in bore 12. Body 10 includes a first end 13 and a second end 14, and preferably includes female threads 15 at each end. In addition, bore 12 includes a valve receptacle 16, a spring receptacle 26, an eccentric gearbox receptacle 36, and a guide groove 46, all described in detail below.

[0011] Flow tube 50 comprises a cylindrical tube having a first end 53 and a second end 54. The outer surface of flow tube 50 includes a first, annular extension 56 spaced a first distance from first end 53 and a second, non-annular extension 58 spaced a further distance from first end 53. In addition, the outer surface of flow tube 50 includes an outwardly extending follower pin 59 between annular extension 56 and non-annular extension 58.

[0012] Referring still to Figure 2 and in particular to bore 12 in body 10, valve receptacle 16 comprises a first increased diameter portion in bore 12. Valve receptacle 16 is bounded by a lower, frustoconical shoulder 17 and an upper, annular shoulder 18. The inside diameter of valve receptacle 16 is greater than the outer diameter of flow tube 50, creating a chamber 19 therebetween. A closure element 20 is housed in chamber 19, along with a spring 22. Closure element 20 is pivotally mounted such that it can pivot about a transverse axis between a closed position, shown in Figure 1, in which it bears on annular shoulder 18, and an open position, shown in Figure 2. In its closed position, closure element 20 preferably substantially obstructs the flow of fluid through bore 12 and in its open position it does not. It will be understood that the closed and open positions need not be completely closed or completely open. In other words, the closed and open positions may be merely relative; namely, the closed position being one in which less fluid is allowed to pass than is allowed in the open position. Spring 22 is preferably mounted between closure element 20 and body 10 such that it bears on closure element and urges it into its closed position. Spring 22 is shown as a coil spring, but it will be understood that spring 22 can comprise any suitable biasing member.

[0013] Spring receptacle 26 comprises a second increased diameter portion in bore 12 spaced farther from end 13 than valve receptacle 16. Spring receptacle 26 is bounded by a lower annular shoulder 27 and an upper annular shoulder 28. The inner diameter of spring receptacle 26 is greater than the outer diameter of flow tube 50, creating an annular chamber 29 therebetween. A coil spring 30 is preferably disposed in chamber 29 between lower annular shoulder 27 of spring receptacle 26 and annular extension 56 of flow tube 50. Spring 30 is preferably sized such that it is compressed and urges flow tube 50 away from first end 13 even when annular extension 56 bears on upper annular shoulder 28.

[0014] Eccentric gearbox receptacle 36 comprises a third enlarged portion in bore 12 and is spaced farther from end 13 than spring receptacle 26. Eccentric gearbox receptacle 36 comprises a lower portion 37 and an upper portion 38. Lower portion 37 houses at least one and preferably a plurality

of drive motors 40, gearboxes 42, and gears 44. Upper portion 38 houses a rotating sleeve 46. Rotating sleeve 46 includes a looped groove 48, which includes a helical portion 47, a short, transverse portion 51, and a straight portion 49. Looped groove 48 receives follower pin 59 on flow tube 50. When closure element 20 is in the closed position shown in Figure 1, follower pin 59 is disposed at a junction between straight portion 49 and helical portion 47.

[0015] Drive motors 40, gearboxes 42, gears 44 and rotating sleeve 46 are preferably operably connected such that power supplied to drive motors 40 causes motors 40 drive gearboxes 42, which in turn drive gears 44, which in turn cause rotating sleeve 46 to rotate about the axis of body 10 and flow tube 50. Figure 3 is a cross-sectional view along the axis of the device with the rotating sleeve 46 removed so as to show the plurality of gearboxes 42 and gears 44. Figure 3 also illustrates the extension of follower pin 59 from the outer surface of flow tube 50.

[0016] Guide groove 46 extends longitudinally along a portion of bore 12 and receives non-annular extension 58 of flow tube 50. Referring briefly to Figures 4 and 5, guide groove 46 preferably is wide enough to include at least a pair of retaining members 68. Retaining members 68 are actuable between an open position, shown in Figure 4, and a closed position, shown in Figure 5. In their closed position, retaining members 68 engage extension 58 so as to prevent flow tube 50 from moving relative to body 10.

[0017] Retaining members 68 and drive motors 40 receive electrical power from electrical leads 7, 9, respectively. Conductors 7, 9 preferably enter body 10 through electrical penetrator 8. Conductors 7, 9 electrically connect to a local control unit 100, which is in turn electrically connected to a remote control unit 102.

[0018] A plurality of seals 70 are preferably provided between body 10 and flow tube 50 so as to isolate guide groove 46, eccentric gearbox receptacle 36, and spring receptacle 26 and prevent the ingress of fluid thereinto.

Operation

[0019] When it is desired to open bore 12 and allow fluid flow therethrough, a preferred first step is to equalize pressure on both sides of closure element 20. With pressure equalized, power is supplied to motors 40 via conductors 9. Motors 40 drive gearboxes 42, which in turn advance gears 44, causing sleeve 46 to rotate such that follower pin 59 enters the helical portion 47 of loop 48. As sleeve 46 rotates, helical groove 47 bears on pin 59, urging flow tube 50 toward first end 13 of body 10. Because flow tube 50 is prevented from rotating by engagement of extension 58 with

guide groove 46, the rotation of sleeve 46 causes flow tube 50 to advance longitudinally through body 10. As flow tube 50 advances relative to body 10 in response to the force applied by rotating sleeve 46, annular extension 56 compresses spring 30 and first end 53 bears on closure element 20, forcing it open. If pressure is not equalized before the opening sequence, more power may be required to open the valve.

[0020] When the opening process is complete, the tool is in the position shown in Figure 2. Specifically, end 53 of flow tube 50 rests on frustoconical shoulder 17 and closure element 20 is contained between body 10 and flow tube 50. Bore 12 is open along the length of the tool, spring 30 is compressed, and follower pin 59 rests at the juncture of helical portion 47 and straight portion 49, as shown in phantom. At this point, power is supplied to retaining members 68, causing them to come together and engage extension 58 of flow tube 50 so as to prevent it from moving axially within body 10. Rotation of sleeve 46 is then preferably continued, without further advancing flow tube 50, as follower pin 59 traverses transverse portion 51 of loop 48, until follower pin 59 rests at the juncture of transverse portion 51 and straight portion 49, as shown in Figure 2.

[0021] Because the present invention is normally closed, it is a fail-safe valve. Once the device has attained the open state shown in Figure 2, flow can continue through it until either the device is closed deliberately, the power supplied to retaining members 68 is interrupted, or retaining members 68 fail. When any of these events occurs, retaining members 68 cease to hold extension 58 and thus cease to prevent flow tube 50 from moving axially. This allows spring 30 to drive flow tube 50 away from first end 13. As flow tube 50 advances toward second end 14, follower pin 59 traverses straight portion 49 of loop 48. Flow tube 50 is sized such that when annular extension 56 bears on upper annular shoulder 28, its first end 53 clears upper annular shoulder 18, allowing closure element 20 to fully close bore 12.

[0022] Because the device preferably includes a plurality of motors 40, a plurality of gearboxes 42, and a plurality of gears 44, it is multiply redundant, ensuring that it remains operable even in the event that one or more of its components fail. In addition, the gear train may be fitted with multiple slip clutches that will allow the device to operate even if one or more of the redundant drive motors fail.

[0023] Retaining members 68 can be any electrically actuable device and are shown as a pair of electrically actuated dogs. In a preferred embodiment, retaining members 68 each comprise at least one flux carrier in conjunction with at least one coil. The coils are connected to conductors 7.

When power is supplied to the coils, they induce flux in the flux carriers, which in turn advance toward extension 58 and ultimately engage it. By using electrical actuation and electrical power, the present device avoids the need for hydraulic systems.

[0024] Flow tube 50 preferably includes a static sealing member at its first end 53, which forms a seal with frustoconical shoulder 17 when the device is open. Flow tube 50 can be rotated to remove deposits that would otherwise impede travel of the tube. In some embodiments, flow tube 50 includes a toothed cutting edge to facilitate removal of deposits.

[0025] In still another alternative embodiment, the relative positions of the drive mechanism and spring 30 may be reversed, such that the flow tube is pulled into the open position against the spring force. In this embodiment it is still preferred that the device be normally closed, so that it can function as a fail-safe device. Nonetheless, it is contemplated that in other embodiments, the configuration may be modified such that the device is normally open. In these embodiments, the relative positions of spring 30 and the drive mechanism may again be such that the drive mechanism either pulls or pushes the flow tube into the closed position.

[0026] While certain preferred embodiments of the present invention has been shown and described, it will be understood that a variety of modifications could be made thereto without departing from the scope of the present invention. For example, the guiding and retaining functions performed by extension 58 could be performed by separate elements. Closure element 20, shown above as a single component could comprise multiple components and/or could operate in various other ways. For example, closure element 20 could comprise a shutter-type closure, a ball valve, a stopcock-type closure, or any other suitable closure device. Likewise, the spring-loaded pivoting mechanism described above could comprise any suitable biasing means such as are known in the art.

[0027] The drive mechanism described above as formed by the combination of gears, rotating sleeve, and follower pin could be replaced with a drive mechanism comprising solely gears, with the drive motors rotating a set of gears to either directly or indirectly advance the flow tube. For example, the flow tube could include gear teeth on a portion of its outer surface. Similarly, a plurality of powered drive mechanisms can be included and can include one-way drive clutches. The drive mechanism(s) can be configured so as to allow nonfunctioning drive mechanisms to be mechanically decoupled.

[0028] Coil spring 30 can be replaced with a biasing means that is better suited to operate in tension, rather than in compression, if desired. Flow tube 50 can be replaced with a non-tubular element, although a tubular element is preferred because it is mechanically robust and protects the various components of the device from contact with the fluid. Similarly, retaining members 68 could be replaced with a single member, or multiple members, mounted inline with extension 58, which when face to face with extension 58 can retain extension 58 when energized.

[0029] The embodiments described herein are exemplary only and are not limiting. One skilled in the art will understand that the mechanisms described herein could each be replaced with alternative mechanisms, so long as the invention is within the scope of the claims that follow. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims which follow, the scope of which shall include all equivalents of the subject matter of the claims. Also, in the claims that follow, the sequential recitation of steps is not intended to require that the steps be performed in the order recited, or that any given step be completed before another step is begun.